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DEVELOPMENT OF A RELIABILITY ANALYSIS FOR GASOLINE-ENGINE-DRIVEN FORK-LIFT TRUCKS

March 1971

Prepared for
U.S. ARMY MOBILITY EQUIPMENT COMMAND
4300 GOODFELLOW BOULEVARD
ST. LOUIS, MISSOURI 63120

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This report describes the data-collection effort and identifies the types of data on fork-lift trucks and other materials-handling equipment that are avail-

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March 1971

Prepared for

U.S. Army Mobility Equipment Command
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by

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CHAPTER ONE

INTRODUCTION

1.1 PURPOSE OF REPORT

The purpose of this report is to provide the U.S. Army Mobility Equipment Command (USAMECOM) with information and data relevant to gasoline-engine-driven (GED), warehouse-type fork-lift trucks. The information presented in this report outlines a six-month study under Contract DAAK01-70-D-4142, Delivery Order 0001. The objectives of this study were as follows:

- To prepare a Standard Part A of a Reliability Record for the family of GED fork-lift trucks
- To prepare a Reliability Record, Parts A and B, for the 6000-pound GED truck in accordance with AMCR 702-8
- To prepare a failure modes, effects, criticality, and avoidance analysis for the fork-lift-truck family

The results of this study are described in three documents:

- Reliability Record for Gasoline-Engine-Driven Fork-Lift Truck Family
- Reliability Record for 6000-Pound Gasoline-Engine-Driven Fork-Lift Truck
- Failure Modes and Effects Analysis for Gasoline-Engine-Driven Fork-Lift Truck Family

This report documents the entire study and provides additional information not contained in the individual documents.

1.2 CONTENTS OF REPORT

This report consists of five chapters. Chapter One briefly outlines the content of the three other documents prepared under this contract.

Chapter Two presents general conclusions and recommendations resulting from this study. These are based on observations and data analyses made throughout the study.

Chapter Three outlines the data-collection effort and describes the types of data on fork-lift trucks and other materials-handling equipment that are available at various CONUS depots and can be used for similar reliability analyses.

Chapter Four describes the mission-profile development for the GED fork-lift truck. It documents the approach used and describes a typical fork-lift-truck mission.

Chapter Five presents the results of the reliability, maintainability, and availability analyses conducted for the family of GED fork-lift trucks. It also presents the results of additional analyses made to classify the data and to add additional information that might be useful in fork-lift-truck management.

1.3 RELIABILITY RECORD

As part of this study, a Standard Part A of a Reliability Record for Gasoline-Engine-Driven Fork Lift Trucks was prepared. This record, prepared in accordance with AMCR 702-8, contains the following information for the family of GED fork-lift trucks:

- A general description of the GED warehouse fork-lift truck
- A general profile of functions that must be performed by the trucks and their subsystems
- A statement of a typical mission for the family, indicating the percentage of time during the mission that the various systems function
- A definition of failure based on how failure affects the accomplishment of the stated mission
- A list of documents required in the preparation of a Reliability Record
- A reliability block diagram depicting the relationship between the reliability of the fork-lift truck and its major systems and subsystems
- Quantitative reliability and maintainability data for the components of the fork-lift-truck family

The Reliability Record provides a basis for evaluating the reliability of any member of the family of fork-lift trucks. It contains a generalized block diagram and outlines the procedure for generating a discrete record for a member of the family. It provides a compilation of reliability information on the family of GED fork-lift trucks and their subsystems and major components. The family of fork-lift trucks for which this record was prepared includes the 2,000-, 4,000-, 6,000-, 15,000-, and 20,000-pound models.

A discrete reliability record was also prepared for the 6,000-pound fork-lift truck. For this record, the general model developed for the family record was used after being tailored to the 6,000-pound truck. An assessment of the reliability, maintainability, and availability of the 6,000-pound truck is presented in this record.

1.4 FAILURE MODES AND EFFECTS ANALYSIS

A failure modes and effects analysis (FMEA) for a gasoline-engine-driven fork-lift truck was prepared. This FMEA is the result of a systematic examination of all the fork-lift-truck systems and components to identify: (1) the modes in which they could fail, and (2) the potential effect of these failures on the successful completion of the mission. This analysis also included a criticality projection that entailed an assessment of the relative criticality of each failure mode to the performance of the mission and to safety of operation.

The FMEA was prepared after a detailed review of various fork-lift-truck maintenance and parts manuals and automotive manuals. The analysis also incorporated the observations and experience gained in the field data-collection effort.

CHAPTER TWO

CONCLUSIONS AND RECOMMENDATIONS

2.1 CONCLUSIONS

The primary conclusion to be drawn from this study is that there are sufficient data in the TAERS program to evaluate the reliability of gasoline-engine-driven fork-lift trucks. The data are amenable to reliability, maintainability, and availability computations, and are reasonably well maintained by the depots. This conclusion applies to other items of materials-handling equipment that are subject to TAERS reporting requirements.

It is also concluded that the failure-data collection form used in this study is adequate for recording reliability, availability, and maintainability data in accordance with the TAERS data format.

The conclusion drawn from the preparation of the Failure Modes and Effects Analysis was that the general design of gasoline-engine-driven fork-lift trucks appears to be quite conventional and that there are no major design deficiencies. The observed reliability assessed for the 6000-pound truck tends to substantiate this. The data that were developed can be used, however, in efforts to improve component reliability.

2.2 RECOMMENDATIONS

ARINC Research Corporation believes that a logical next step is to use the reliability, maintainability, and availability data presented in the Reliability Records for future logistics planning. These data are key inputs to provisioning determinations and maintenance planning. In past studies, ARINC Research has developed models and computer programs that are capable of using reliability, maintainability, and availability data, along with cost, mission requirements, and schedule requirements, to assist in determining (1) whether it is more cost-effective to throw away or repair components; (2) at which level of maintenance it is most cost-effective to repair components; (3) the optimum distribution of components in the supply system with a given level of funding; and (4) a measure of supply effectiveness for a given level of funding or, conversely, the cost for a desired level of supply effectiveness.

Analyses that can be performed with the data that are available as a result of this study include the following:

- Correlation of vehicle or component failure rates with manufacturer. Such a correlation could easily be made with the data collected by ARINC Research. This could provide MECOM with an appreciation of which manufacturers are producing the more reliable vehicles or vehicle components and could aid in selecting future vendors.

- Determination of failure distributions for components of fork-lift trucks. In our evaluation of the reliability of the fork-lift truck family, we assumed that the failure distributions of all components were exponential; that is, the failure rate of the components was assumed to be constant with time. This assumption is valid even when the component population under study has an underlying distribution controlled by wearout but the sample observed comprises many age groups as a result of replacing failures; this condition is met by the data samples involved in this study. We can, however, determine from the data we collected the exact nature of the failure distributions of many of the major components. This information could be used as a basis for developing an optimum maintenance policy for each major component, with availability, cost, and unscheduled shutdowns used as variables in developing the maintenance policy.
- Correlation of fork-lift-truck component failure rate with vehicle age. The age of the fork-lift trucks used in the reliability evaluation varied from relatively new trucks to 19-year-old trucks. Personnel at the three depots from which we collected data were of the opinion that equipment age was the determining factor for reliability. The scope of this study did not include a determination of the nature of the age-reliability relationship. However, with the data collected in the study, such an evaluation could be made. We believe that this evaluation could benefit MECOM in that it would permit determining equipment and/or truck service life. It could also provide the basis for determining part-replacement intervals, which could be the basis for preventive-maintenance schedules.

It is our opinion that MECOM should seriously consider these recommendations in light of the investment already made to produce the data.

CHAPTER THREE

DATA COLLECTION

3.1 DATA AVAILABILITY

To determine the availability of data that could be used to quantify the reliability, maintainability, and availability of the fork-lift truck, ARINC Research conducted an initial survey of three depots believed to have a significant quantity of fork-lift trucks:

- The Atlanta Army Depot (ATAD), Forest Park, Georgia
- The Red River Army Depot (RRAD), Texarkana, Texas
- The Defense General Supply Center (DGSC), Richmond, Virginia

It was determined that these three locations had a significant quantity of trucks (a total of 515) and that the data they maintained were adequate for use in computing the desired indices. The nature of the data and our plan for collecting the data were subsequently outlined in a report entitled *Data Collection and Implementation Plan for Gasoline-Engine-Driven Fork-Lift Trucks,* August 10, 1970.

The data at the two Army depots are primarily those recorded in the TAERS (The Army Equipment Record System) Program. Maintenance data are available on DA Form 2407, Maintenance Request Forms. Utilization data (operating hours) are available on DA Form 2408-1, Equipment Daily or Monthly Log, or similar forms. The data available at DGSC were recorded on similar forms. The nature of all of the data-recording forms at the three depots was outlined in the aforementioned Data Collection Plan.

Maintenance and utilization data were available from ATAD and DGSC for an 18-month period — January 1969 through June 1970. The data at RRAD were available for the 12-month period July 1969 through June 1970. Table 1 provides a description of the various trucks at the three depots and an indication of the quantities of the trucks at each depot. Data from 515 trucks were collected. The table shows a total of 489 trucks. There were 26 trucks at DGSC for which we did not obtain a Federal Stock Number. These were included in the data sample but are not shown in Table 1.

Each depot had reasonably well-maintained data files. Utilization data were generally kept in a folder or binder for each truck. The maintenance data at RRAD and DGSC were filed by truck serial number, which made it easy to record all the maintenance data on an individual truck at one time and permitted easy access to specific information on individual trucks.

We found that good records were kept by each depot visited. The records reviewed at ATAD were excellent and required very little supplemental effort to extract the data required for our study.

Table 1. **DESCRIPTION OF GASOLINE-ENGINE-DRIVEN FORK-LIFT TRUCK FAMILY**

Manufacturer	FSN	Capacity* (lbs.)	Lift Height (inches)	Type of Tires	Location Distribution		
					ATAD	RRAD	DGSC
Clark	3930-956-0094	4,000	144	Solid rubber			14
Minneapolis-Moline	3930-724-3570	4,000	144	Pneumatic		4	
Minneapolis-Moline	3930-064-5868	4,000	144	Pneumatic	3	25	
Minneapolis-Moline	3930-064-6564	4,000	144	Solid rubber	9		2
Yale & Towne	3930-271-1449	2,000	130	Solid rubber	1		5
Towmotor	3930-292-1100	6,000	127	Solid rubber			6
Towmotor	3930-292-1098	6,000	168	Solid rubber	3		
Clark	3930-542-2175	4,000	100	Solid rubber	7		
Clark	3930-542-2176	4,000	144	Solid rubber	10		
Baker	3930-738-5938	6,000	168	Pneumatic	5		2
Clark	3930-781-3857	2,000	100	Solid rubber	3		
Clark	3930-965-0093	4,000	100	Solid rubber			2
Clark	3930-915-0093	4,000	100	Solid rubber			2
Clark	3930-954-9311	4,000	100	Solid rubber	12	6	
Clark	3930-954-1303	4,000	144	Solid rubber	21	22	6
Allis Chalmers	3930-958-3684	6,000	168	Pneumatic	17	9	
Baker	3930-879-6870	6,000	168	Pneumatic			4
Minneapolis-Moline	3930-064-5869	6,000	168	Pneumatic			1
Towmotor	3930-781-3856	4,000	100	Solid rubber		5	1
Towmotor	3930-781-3855	4,000	144	Solid rubber	91	12	25
Towmotor	3930-073-9222	4,000	144	Pneumatic		8	
Service-Caster	3930-214-1025	4,000	180	Solid rubber	1		
Clark	3930-J02-2113	4,000	212	Solid rubber			1
Clark	3930-266-8955	4,000	144	Pneumatic			6
Towmotor	3930-P00-8120	3,000	130	Solid rubber		1	
Allis Chalmers	3930-203-2842	2,000	130	Pneumatic		3	
Clark	3930-203-2842	2,000	130	Pneumatic		3	
Clark	3930-266-8961	4,000	144	Solid rubber			1
Towmotor	3930-752-9464	4,000	144	Solid rubber		55	
Automatic Transportation	3930-679-4457	10,000	100	Solid rubber		3	
Hyster	3930-J28-0598	15,000	100	Pneumatic		1	
Hyster	3930-897-4632	15,000	210	Pneumatic	5	7	2
Clark	FSC-3930-NFN	20,000	210	Pneumatic		1	
Allis Chalmers	3930-1208-3242	5,000	144	Pneumatic		2	
Towmotor	3930-678-9917	4,000	100	Solid rubber			10
White	3930-P00-9608	4,000	100	Solid rubber		16	
White	3930-P00-9607	6,000	136	Pneumatic		15	
B.B. Lift Corporation	3930-209-2841	6,000	168	Pneumatic		1	
Gerlinger	3930-514-3477	15,000	210	Pneumatic		1	
Towmotor	3930-273-8225	4,000	144	Solid rubber			3
Yale	3930-214-1026	4,000	144	Solid rubber			5
Hyster	3930-238-4411	10,000	210	Pneumatic			1
Hyster	3930-038-4410	10,000	–	–		1	
Baker-York	3930-209-3242	6,000	–	–		1	
*Rated with 24″ load center.				Total	188	202	99

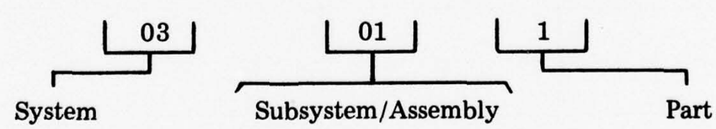
3.2 DATA-COLLECTION METHOD

Two basic data-collection forms were used in this study. Figure 1 shows the form (ARINC B01-01 F/L F1) used to collect the monthly operating-time information. The form's heading was general, so that the form could accommodate the data found at any of the depots.

Figure 2 shows the form (ARINC B01-01 F/L F2) used to collect the failure data. The columns in this form are self-explanatory. (The referenced Data Collection Plan outlines the use of this and the utilization form.)

Only data on part failures were collected. If a part was replaced or serviced as a part of a scheduled maintenance action, it was not considered a failed part and was not recorded on our data form. Whenever a part failed and a nonscheduled maintenance action resulted, the information was recorded on the data form. Additionally, whenever a failed part was discovered during a scheduled maintenance action and was repaired or replaced, a record was entered on the Failure Data Form. As a general rule, a failure was defined as any incident that deadlined the vehicle during operation or that resulted in an unscheduled replacement or repair action.

The Failure Data Form was well-suited to the purpose of collecting failure and maintenance data from the maintenance forms maintained at the depots. Columns 8 through 11 were applicable only to the Army Depot data and were used to record the appropriate codes in accordance with the TAERS Program Manual (TM 38-750). The collection of data from the 515 trucks at the three locations required two men for approximately eight weeks. Data recording was facilitated by the development of functional-group codes for each part of the fork-lift truck. The four-digit codes given in TB-750-93-1 (Functional Grouping Codes: Combat Tactical, and Support Vehicle and Special Purpose Equipment) were the basis for these codes. A fifth number was added to these four-digit codes to identify a part to a subsystem/assembly and a system. For example, all parts belonging to the engine system used "03" as the first two digits. The next two digits indicated the subsystem assembly. The code 0301 was the carburetor assembly of the engine system. The part designation was made by adding a number to this four-digit code. For example, "03011" is the carburetor gasket. The coding scheme can be illustrated as follows:



The development of these codes made it much easier and faster to record the data on the Failure Data Form since the part name did not have to be written. Use of these codes also permitted subsequent computer processing of the data.

MONTHLY UTILIZATION: FORK LIFT FAMILY		
1. FSN ______	4. S/N ______	7. TMP NO ______
2. MFG ______	5. AGE ______	8. MAST HT ______
3. CAP ______	6. MFG NO ______	9. ARMY/DSA MOD ______

10	11	12
Month/Year	Operating Hours	Remarks

Figure 1. **MONTHLY UTILIZATION FORM**

ARINC B01-01 F/L F1

FAILURE DATA: FORK LIFT FAMILY

1. Capacity________________ 2. MFG____________________ 3. FSN__________________

4	5			6	7	8	9	10	11	12	13	14		15	16	17
Fork Lift Serial Number	*Occurrence*			*Failed Part*	FSN/Part Number	Detected Failure Code	First Indication of Trouble Code	Action Taken Code	Failure Code	Total Man-Hours to Complete	Total Clock/Time to Complete	Back in Commission		Date Ordered	Date Parts Received	Comments
	Date	Time	Hours	Name								Date	Time			

Figure 2. **FAILURE-DATA FORM**

ARINC B01-01 F/L F2

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CHAPTER FOUR

MISSION-PROFILE DEVELOPMENT

4.1 MISSION PHASES

In assessing the reliability of a system such as a fork-lift truck it is necessary to describe the operational profile of the system and the environmental conditions prevailing during the various periods of operation. The mission profile is defined in terms of the elapsed mission times or mission phases in which the system is operative, and the duration of each phase. The sequence of functions necessary for success and the duty cycles of items within the system are also elements of the mission profile that must be defined.

A typical mission profile for the family of gasoline-engine-driven fork-lift trucks was developed by using the information contained in the operator's manuals as well as field observations of typical warehouse operations. The mission of a fork-lift truck was established as a typical day's operation in a depot warehouse. It was determined that a typical 8-hour shift operation was more standard than any single operation involving the transfer of a load from one position to another. The mission was divided into seven basic functions as described in Figure 3.

Function	Description
Start	Engaging the starting motor and starting the truck's engine
Idle	Allowing the engine to run with no load imposed until the normal operating temperature is reached
Drive	Driving the truck to the load to be picked up
Lift	Positioning the truck, tilting the forks, and lifting the load onto the truck
Transport	Moving the load from the position from which it was picked up to the position at which it is to be deposited
Deposit	Positioning the load at its destination and leaving it
Stop	Turning off ignition and stopping engine

Figure 3. **FORK-LIFT-TRUCK MISSION FUNCTIONS**

The occurrence of these functions was observed during typical warehouse operations by field engineers equipped with tape recorders. The engineers observed many operations and recorded the nature of each. These recordings documented the time durations of each function, estimates of distances traveled during each operation, estimates of load weights during each operation, and other pertinent information. A comprehensive review of these observations permitted the development of a mission profile that describes a typical single-shift operation of a fork-lift truck cycling through the seven phases described in Figure 3. Table 2 summarizes the results of this development.

Table 2. **DISTRIBUTION OF TIME, BY FUNCTION, DURING ONE MISSION**

Function	Duration per Occurrence (minutes)	Frequency of Occurrence	Total Time (minutes)	Percentage of Operating Time
Start	0.25	8	2.0	0.7
Idle	5.00	2	10.0	3.6
Drive	0.75	89	66.7	23.8
Lift	0.75	89	66.7	23.8
Transport	0.75	89	66.7	23.8
Deposit	0.75	89	66.7	23.8
Stop	*0.16	8	1.3	0.5
Total Operating Time			280.1	100.00
Operating Time			**4.66 hours	
Non Operating Time			3.34 hours	
Mission Time			8.00 hours	

*Assumed value.
**Rounded to 5 hours for the reliability-assessment computations.

Analysis of the utilization data collected during the data-collection phase of this study revealed that the sample of 515 fork-lift trucks averages 4.66 hours, or approximately 280 minutes of operation per day. Therefore, the total mission time for all functions is approximately 280 minutes.

A typical day's operation can be described as follows: The operator makes a visual check of such items as oil level, radiator water level, battery condition, belt condition, lights, and other daily preventive-maintenance services. He starts the truck and allows it to idle until it reaches operating temperatures. He then proceeds to his first load, lifts it, transports it to its destination, and deposits it. He goes through several cycles of driving to a load through depositing it before he stops the truck.

The truck is always stopped for a break in the morning, for the lunch break, for a break in the afternoon, and at the end of the day. In addition, field observations indicated that the truck was started and stopped, for various reasons, on the average of four other times. Therefore, the frequency of the Start and Stop functions during a typical day was determined to be eight. Only twice during a day's operation was the warm-up idle function observed to occur — at the beginning of the shift and after the lunch break.

The average time for a truck to cycle through the Drive, Lift, Transport, and Deposit functions was observed to be three minutes. The Drive and Transport functions were observed to consume the same amount of time — slightly less than three quarters of a minute. The Lift and Deposit functions also took approximately the same amount of time. Therefore, since

$$t_{(\text{drive, lift, transport, deposit})} = 3 \text{ minutes}$$

and

$$t_{\text{drive}} = t_{\text{transport}} = 0.75 \text{ minute}$$

then

$$\begin{aligned} t_{\text{lift}} + t_{\text{deposit}} &= 3 \text{ min} - (t_{\text{drive}} + t_{\text{transport}}) \\ &= 3 \text{ min} - 1.5 \text{ min} \\ &= 1.5 \text{ min} \end{aligned}$$

and

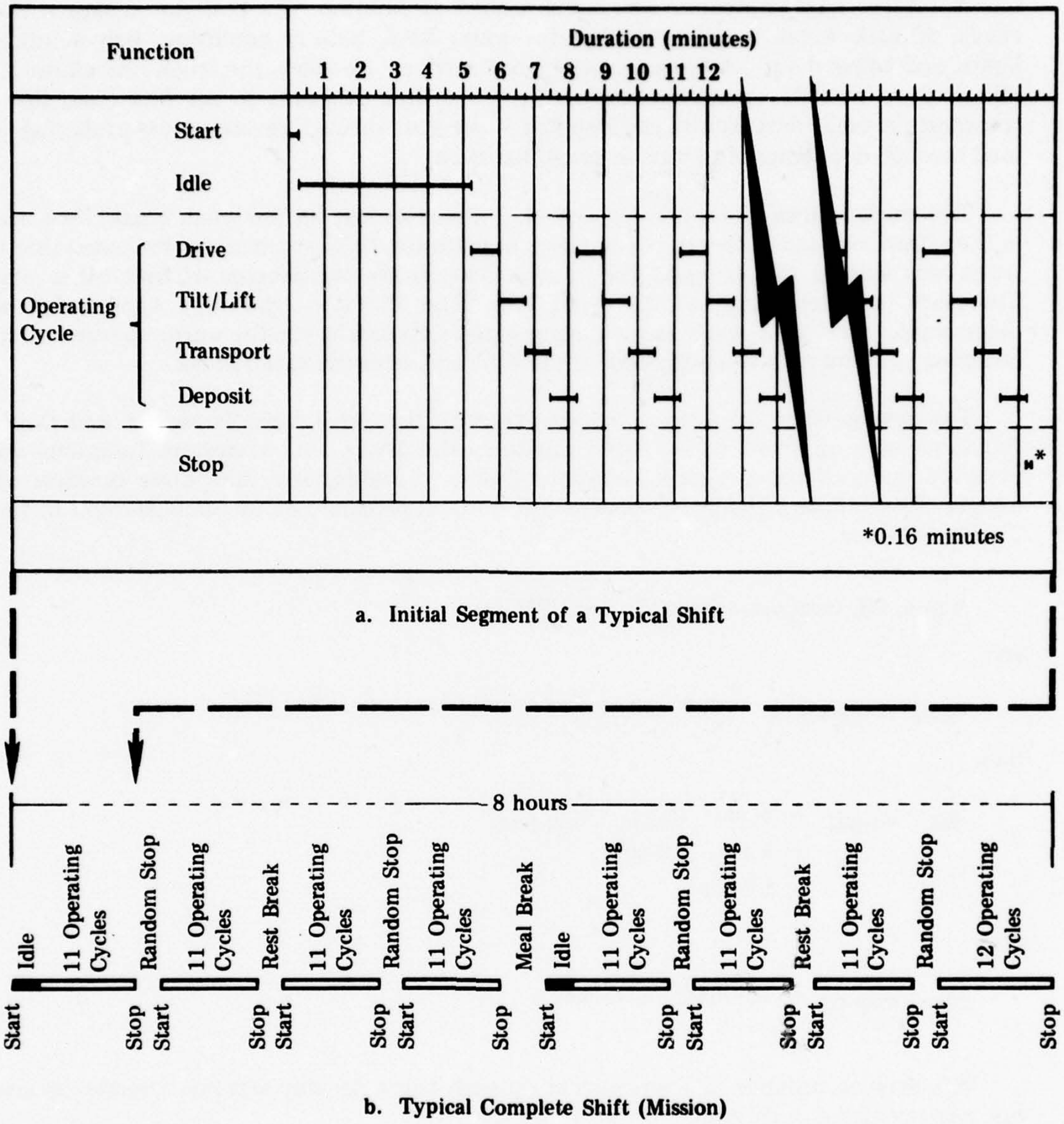
$$t_{\text{lift}} = t_{\text{deposit}} = 1.5 \text{ min}/2 = 0.75 \text{ min}$$

The average number of loads moved by each truck per day was not directly observed but was calculated as follows:

$$\begin{aligned} \text{Number of loads} &= \frac{280 \text{ min} - (t_{\text{start}} + t_{\text{idle}} + t_{\text{stop}})}{t_{\text{drive}} + t_{\text{lift}} + t_{\text{transport}} + t_{\text{deposit}}} \\ &= \frac{280 \text{ min} - (2 + 10 + 1.3) \text{ min}}{3 \text{ min}} \\ &\cong 89 \end{aligned}$$

Figure 4 is a graphical presentation of the mission profile that was developed.

Therefore, with these times established as the mission times for the various functions, the percentage of the total mission time for each function was computed.



Total Operating Time	5 hours
Total Nonoperating Time	3 hours
Two 0.25-hour rest breaks	
One 1.00-hour meal break	
Four 0.375-hour random stops	
Total Shift (Mission) Time	8 hours

Figure 4. **MISSION PROFILE**

This makes it possible to establish the percentage of the time each system, subsystem/assembly, and component in the fork-lift truck operates during a mission or any period of time.

A component mission-profile matrix indicating the function in which each component operates was prepared to determine the percentage of the total mission time each component operates. For instance, the starting motor operates only during the Start function; therefore, it operates (as noted in Table 2) 0.70 percent of the time. The torque converter in the transmission system, however, operates during the Drive and Transport functions, or 47.6 percent of the total mission time. This matrix is shown in Appendix A, with the component/assembly identified by the appropriate Functional Grouping Code. Functional grouping codes are also identified in Appendix A.

Some components do not operate throughout the duration of certain functions, or their operation is unique to a particular function. For example, an inching pedal (12029) is not used throughout the entire lift or deposit functions, nor is the horn operated during any specific function. In these instances, estimates of the proportion of operating time during certain functions, or frequency of operation during a day's operation, were made on the basis of field observations, and an additional modifier was used. These are appropriately identified in the matrix in Appendix A.

4.2 SUPPLEMENTARY FIELD OBSERVATIONS

Throughout the field data-collection effort, the operation and management of fork-lift trucks was observed. This section documents these observations for the benefit of engineers and analysts who have not had the opportunity for such observations.

4.2.1 Maintenance of Fork-Lift Trucks

Chapter Two described the maintenance-data records used for the reliability analyses conducted during this study. These data records were taken from TAERS/TAMMES data forms and represent a most comprehensive compilation of maintenance and failure data collected at the depots.

Additional data that are not formally recorded but can provide added insight into the maintenance of these trucks are the service-call data. Service calls are requested by the operator or his supervisor whenever trouble is experienced with a fork-lift truck. A roving mechanic answers the service call and either repairs the truck or deadlines it for return to the maintenance shop for repairs.

Whether or not he can "fix" the truck, he fills out a service-call form that records the date and time of the call, the truck number, the type of trouble, a brief description of his action, and the repair time. Records of these service calls are not generally maintained. At most, they are kept for 30 days. Service-call forms contain little information that can be used directly for an evaluation of reliability, maintainability, or availability, but they can provide an insight into the types of troubles that can be handled at the user location. Appendix B lists typical machine service-call records collected at DGSC over a 30-day period.

None of the lift operators at any of the locations (ATAD, RRAD, and DGSC) was observed making repairs (minor or otherwise) to a lift. Interviews with the operators and

their supervisors further indicated that operators do not repair their lifts. Whenever trouble is experienced, the service mechanic is called. The only maintenance performed by the operator is the daily preventive maintenance specified in the operator's manual.

4.2.2 Operation of Fork-Lift Trucks

In general, it was observed that the fork-lift trucks are operated in accordance with the operating procedures specified in the operator's manual. Each operator performs the prescribed preventive-maintenance services before commencing daily operations. For example: (1) he engages the parking brake and puts the truck in neutral prior to starting; (2) if necessary, he allows the truck to idle until the operating temperature is reached; and (3) he engages the parking brake when lifting or depositing a load.

In no instance was an operator observed to lift a load that exceeded the capacity of the truck he was operating. If a load exceeded the capacity of the truck operating in the area, either the operator or the foreman called in an operator of a truck with the required capacity. The operators were observed to drive at all times with the load as low as possible, maintaining floor clearance, to achieve maximum stability of the load and the truck. For the most part, the operators appeared to be well-trained in the operation of fork-lift trucks and operated them in the manner prescribed by the operator's manual.

An interesting observation passed on by various personnel at the depots was that operators driving new or newly painted and well-maintained trucks were generally more careful in handling them. Operators are inclined to be "harder" on older-looking and less well-maintained trucks. An in-depth analysis of the data collected could determine whether there is a correlation between failure rate and truck age.

CHAPTER FIVE

DATA ANALYSIS

The data-collection effort of this study resulted in the assimilation of approximately 24,000 maintenance actions. These data were subsequently used in the analyses of reliability, maintainability, and availability for the components of the Gasoline-Engine-Driven Fork-Lift Trucks. As discussed in Chapter One, two Reliability Records were prepared. The record for the fork-lift truck family included failure-rate and maintainability data for the components that are included in the family of fork-lift trucks. The record for the 6000-pound fork-lift truck included a reliability analysis of the components, subsystems/assemblies, systems, and the truck itself. It also included a maintainability and availability analysis of the 6000-pound truck. The following subsections briefly outline how the analyses were conducted.

5.1 RELIABILITY ANALYSIS

5.1.1 Component Reliability

The analysis of component reliability was based on the computation of component failure rate, which was found by dividing the number of failures by the number of component operating hours, and on the assumption that failure rate is constant with time. This is expressed mathematically as follows:

$$R_c = e^{-\lambda_c T_c}$$

where

R_c = Component reliability

λ_c = Component failure rate

$$\lambda_c = \frac{\text{Number of component failures}}{\text{Total truck operating hours} \times t}$$

T_c = Component operating time during the mission $\times$ t

= Truck operating time during the mission $\times$ t

t = Percentage of time during a mission that the component operates*

*Determined by using the percentages derived in Table 1 and the mission-profile matrix in Appendix A.

Component-failure-rate computations were made for the family record by including all the utilization and failure data collected. These failure rates can be used to prepare a reliability record for a discrete member of the family (we believe that these rates are the best available estimates).

The component failure rates generated for the 6000-pound fork-lift truck record were based on an assessment of the data gathered from the utilization of the 6000-pound trucks included in the sample selected for this study. Section 5.4 indicates the number of operating hours and trucks in this population.

Reliabilities of the fork-lift-truck components were computed on the basis of mission operating hours as explained in Section 4.1.

5.1.2 Subsystem/Assembly and System Reliability

Subsystem/assembly reliability for the 6000-pound-truck record was computed by multiplying the reliabilities of the components of the subsystem/assembly. Similarly, system reliability was computed by multiplying the subsystem/assembly reliabilities. This procedure assumed a series relationship of all the components and subsystems/assemblies of the truck — a reasonable assumption since redundancies of component functions or subsystem/assembly functions do not exist. A truck has several wheels (tires), spark plugs, etc., but they are not redundant from an operational or a reliability standpoint. The total function of the truck is not aborted with a single failure of a component such as a spark plug, but the truck's operability is degraded and its operation would be stopped if the failure were detected. Therefore, all component failures were considered capable of causing truck failure.

5.1.3 Functional Reliability

Functional-reliability computations on the 6000-pound truck were made for each of the seven functions listed in Section 4.1 by computing the reliabilities of each system for the time period of the function and multiplying the reliabilities of each system required to operate in that function. For example:

$$R_{start} = R_{electrical,\ start} \times R_{engine,\ start} \times R_{fuel,\ start}$$

where

R_{start} = Reliability of start function

$R_{electrical,\ start}$ = Reliability of the electrical system in the start function

$= e^{-\lambda_{electrical} T_{start}}$

where

$\lambda_{electrical}$ = electrical-system failure rate

T_{start} = amount of operating time in start phase

In a similar fashion $R_{engine,\ start}$ and $R_{fuel,\ start}$ are computed.

5.1.4 Mission Reliability

The predicted probability of the 6000-pound truck's successfully completing the mission was computed by taking the product of the seven function-reliability values. This is expressed mathematically as follows:

$$R_{mission} = R_{start} \times R_{idle} \times R_{drive} \times R_{lift} \times R_{transport} \times R_{deposit} \times R_{stop}$$

This result was then modified to account for multiple maintenance actions to yield the observed reliability.

5.2 MAINTAINABILITY ANALYSIS

Mean maintenance man-hours per failure was the maintainability index computed in this study. Mean maintenance man-hours for each component were computed for the family record by using the following equation:

$$\text{MMMH} = \frac{\text{Number of maintenance man-hours}}{\text{Failures}}$$

For the 6000-pound-truck record system, maintainability (i.e., mean maintenance man-hours per failure) was computed in a similar manner by using the basic data from the family record — that is, the number of maintenance man-hours and failures for the components of the 6000-pound truck were determined from the data in the family record. For this procedure it is assumed that the amount of maintenance time required to repair a component is independent of the size or capacity of the truck from which the component came. Our review of the design and maintenance procedures of the various trucks in the family convinces us that this assumption is valid.

5.3 AVAILABILITY ANALYSIS

Availability for the fork lift truck is defined as the probability that the truck is operating or is ready to operate at any point in time. The following expression is used to compute availability:

$$A_i \cong \frac{\dfrac{1}{\lambda_i t_i}}{\dfrac{1}{\lambda_i t_i} + \text{MMMH}_i}$$

where

λ_i = failure rate of i^{th} item

t_i = proportion of mission time during which item i operates

MMMH_i = mean maintenance man hours for i^{th} item (equivalent to mean time to repair as explained in the previous section)

This expression is valid when the following conditions apply:

1. A continuous demand for the truck exists during the 5-hour operating period
2. Maintenance personnel are available only during the same 5-hour operating period
3. Maintenance is initiated immediately when failure occurs
4. $MMMH_i \ll \frac{1}{\lambda_i t_i}$

Since these conditions are essentially met in the situation under consideration, the expression provides a reasonable estimate of availability.

5.4 SUPPLEMENTAL DATA ANALYSIS

This section characterizes the nature of the fork-lift-truck sample used in the computation of reliability, maintainability, and availability.

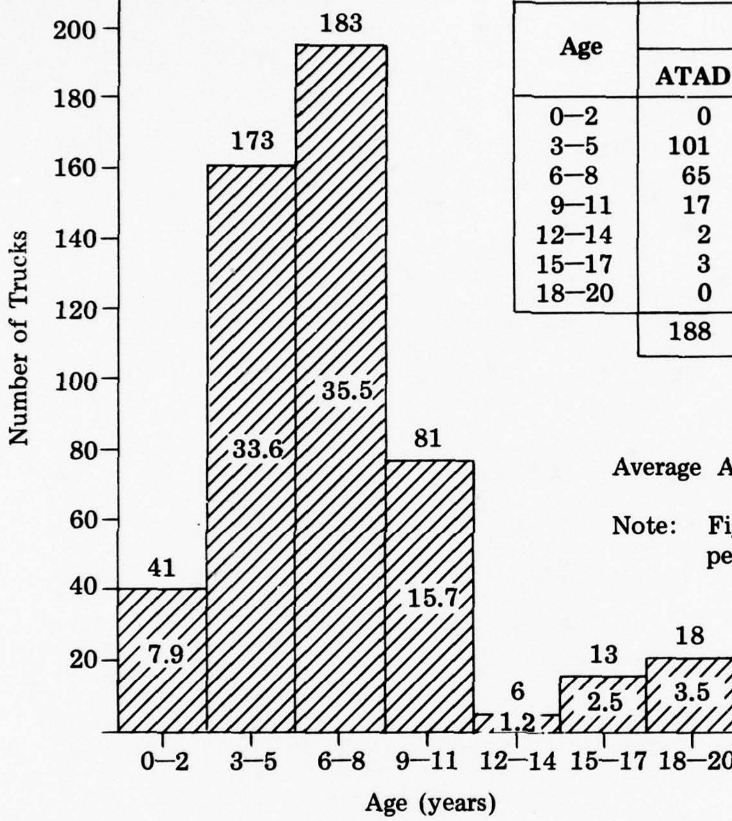
A total of 515 gasoline-engine-driven warehouse-type fork-lift trucks were included in the sample. Table 3 shows the distribution of the various-size trucks in the sample. The majority (approximately 78 percent) of the trucks were of the 4000-pound capacity. This type seemed to be preferred by the depot operations personnel since the range of its lifting capacity generally covered the weight range of the majority of loads typical of a depot warehouse. The 6000-pound-capacity trucks constituted the next highest percentage of the total population (approximately 13 percent).

Table 3. **CAPACITY DISTRIBUTION OF FORK-LIFT TRUCKS**

Capacity (lbs.)	Number of Trucks	Percent of Truck Inventory
2000	17	3.30
3000	1	.19
4000	406	78.83
5000	2	.39
6000	65	12.62
10000	6	1.17
15000	16	3.11
16000	1	.19
20000	1	.19
Total	515	100.00

Table 1 in Chapter Three showed that the sample of trucks were manufactured by 12 different manufacturers. Of these 12, only about six currently produce the majority of gasoline-engine-driven fork-lift trucks in the family of 2000- to 20,000-pound trucks.

The age of the trucks in our sample varied from six months to 19 years. The average age in the total sample of 515 trucks was 6.7 years. Figure 5 is a histogram of the age distribution of the sample. It also shows the numerical distribution by depot location. The Defense General Supply Center had the greatest number of older trucks. DGSC also had the greater number of different Federal Stock Number (FSN) trucks.



Age	Location			Totals
	ATAD	RRAD	DASC	
0–2	0	33	8	41
3–5	101	26	46	173
6–8	65	79	39	183
9–11	17	62	2	81
12–14	2	0	4	6
15–17	3	0	10	13
18–20	0	2	16	18
	188	202	125	515

Average Age = 6.7 years

Note: Figure inside bar represents percent of total.

Figure 5. **AGE DISTRIBUTION OF GED FORK-LIFT-TRUCK SAMPLE**

We did not evaluate the correlation between vehicle age and reliability or the impact of the quantity of FSNs on maintainability. Depot personnel expressed concern about the impact that truck age has on reliability and the impact that many different FSN's have on the ability to maintain the trucks efficiently. With the data we collected, we can conduct such evaluations.

Additional investigations can be made with the data collected. For example, by use of the failure-rate and maintainability data, existing scheduled maintenance activities can be reviewed to determine whether they are being conducted too frequently or not often enough and whether maintenance-activity time standards are realistic.

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APPENDIX A

COMPONENT MISSION PROFILE MATRIX

This appendix presents the matrix from which the mission profile for the gasoline-engine-driven fork-lift truck was developed. It indicates the function or functions for which each component, identified by its Function Group Code, is required to operate. In compiling the matrix, we made assumptions concerning mission time for some components, as follows:

1. The lights and associated accessories are required to operate 25 percent of the total mission time.
2. The horn and its associated accessories are required to operate 2.1 percent of the total mission time.
3. The components associated with the creeping/inching function are used 22 percent of the time during the lift and deposit functions.

These assumptions are based upon the observations made of the operation of the trucks.

Component Mission Profile Matrix

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
0100	X	X	X	X	X	X	
01001	X	X	X	X	X	X	
01002	X	X	X	X	X	X	
01003	X	X	X	X	X	X	
01004	X	X	X	X	X	X	
01005	X	X	X	X	X	X	
01006	X	X	X	X	X	X	
01007	X	X	X	X	X	X	
01008	X	X	X	X	X	X	
01009	X	X	X	X	X	X	
0101	X	X	X	X	X	X	
01011	X	X	X	X	X	X	
01012	X	X	X	X	X	X	
01013	X	X	X	X	X	X	
01014	X	X	X	X	X	X	
0102	X	X	X	X	X	X	
01021	X	X	X	X	X	X	
01022	X	X	X	X	X	X	
01023	X	X	X	X	X	X	
01024	X	X	X	X	X	X	
01025	X	X	X	X	X	X	
01026	X	X	X	X	X	X	

Component Mission Profile

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
0103	X	X	X	X	X	X	
01031	X	X	X	X	X	X	
01032	X	X	X	X	X	X	
01033	X	X	X	X	X	X	
0104	X	X	X	X	X	X	
01041	X	X	X	X	X	X	
01042	X	X	X	X	X	X	
01043	X	X	X	X	X	X	
01044	X	X	X	X	X	X	
0105	X	X	X	X	X	X	
01051	X	X	X	X	X	X	
01052	X	X	X	X	X	X	
01053	X	X	X	X	X	X	
01054	X	X	X	X	X	X	
01055	X	X	X	X	X	X	
01056	X	X	X	X	X	X	
01057	X	X	X	X	X	X	
01058	X	X	X	X	X	X	
01059	X	X	X	X	X	X	
010510	X	X	X	X	X	X	
010511	X	X	X	X	X	X	
010512	X	X	X	X	X	X	
010513	X	X	X	X	X	X	

Component Mission Profile Matrix

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
010515	X	X	X	X	X	X	
0106	X	X	X	X	X	X	
01061	X	X	X	X	X	X	
01062	X	X	X	X	X	X	
01063	X	X	X	X	X	X	
01064	X	X	X	X	X	X	
01065	X	X	X	X	X	X	
01066	X	X	X	X	X	X	
01067	X	X	X	X	X	X	
01068	X	X	X	X	X	X	
01069	X	X	X	X	X	X	
0108	X	X	X	X	X	X	
01081	X	X	X	X	X	X	
01082	X	X	X	X	X	X	
01083	X	X	X	X	X	X	
0109	X	X	X	X	X	X	
0301	X	X	X	X	X	X	
03011	X	X	X	X	X	X	
03012	X	X	X	X	X	X	

Component Mission Profile Matrix

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
03013	X	X	X	X	X	X	
03015	X	X	X	X	X	X	
03016	X	X	X	X	X	X	
0302	X	X	X	X	X	X	
03021	X	X	X	X	X	X	
03022	X	X	X	X	X	X	
03023	X	X	X	X	X	X	
03024	X	X	X	X	X	X	
03025	X	X	X	X	X	X	
0304	X	X	X	X	X	X	
03041	X	X	X	X	X	X	
03042	X	X	X	X	X	X	
04043	X	X	X	X	X	X	
03044	X	X	X	X	X	X	
0306	X	X	X	X	X	X	
03061	X	X	X	X	X	X	
03062	X	X	X	X	X	X	
0308	X	X	X	X	X	X	
03081	X	X	X	X	X	X	
03082	X	X	X	X	X	X	
03083	X	X	X	X	X	X	
03084	X	X	X	X	X	X	

Component Mission Profile Matrix

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
03085	X	X	X	X	X	X	X
03086	X	X	X	X	X	X	X
03087	X	X	X	X	X	X	X
03088	X	X	X	X	X	X	X
0309	X	X	X	X	X	X	X
0312	X	X	X	X	X	X	X
03121	X	X	X	X	X	X	X
03122	X	X	X	X	X	X	X
03123	X	X	X	X	X	X	X
03124	X	X	X	X	X	X	X
03125	X	X	X	X	X	X	X
0401		X	X	X	X	X	
04011		X	X	X	X	X	
04012		X	X	X	X	X	
04013		X	X	X	X	X	
04014		X	X	X	X	X	
04015		X	X	X	X	X	
04016		X	X	X	X	X	

Component Mission Profile Matrix

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
0501		X	X	X	X	X	
05011		X	X	X	X	X	
05012		X	X	X	X	X	
05013		X	X	X	X	X	
05014		X	X	X	X	X	
0503		X	X	X	X	X	
05031		X	X	X	X	X	
05032		X	X	X	X	X	
05033		X	X	X	X	X	
05034		X	X	X	X	X	
05035		X	X	X	X	X	
0504		X	X	X	X	X	
05041		X	X	X	X	X	
05042		X	X	X	X	X	
05043		X	X	X	X	X	
05044		X	X	X	X	X	
0505		X	X	X	X	X	
05051		X	X	X	X	X	
05052		X	X	X	X	X	
05053		X	X	X	X	X	
05054		X	X	X	X	X	
05055		X	X	X	X	X	

Component Mission Profile Matrix

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
0601	X	X	X	X	X	X	X
06011	X	X	X	X	X	X	X
06012	X	X	X	X	X	X	X
06013	X	X	X	X	X	X	X
06014	X	X	X	X	X	X	X
06015	X	X	X	X	X	X	X
0602	X	X	X	X	X	X	X
06021	X	X	X	X	X	X	X
06022	X	X	X	X	X	X	X
06023	X	X	X	X	X	X	X
06024	X	X	X	X	X	X	X
06025	X	X	X	X	X	X	X
06026	X	X	X	X	X	X	X
06027	X	X	X	X	X	X	X
06028	X	X	X	X	X	X	X
06029	X	X	X	X	X	X	X
060210	X	X	X	X	X	X	X
060211	X	X	X	X	X	X	X
060212	X	X	X	X	X	X	X
060213	X	X	X	X	X	X	X
0603	X						
06031	X						
06033	X						

Component Mission Profile Matrix

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
06034	X						
06035	X						
06036	X						
06037	X						
06038	X						
06039	X						
0605	X	X	X	X	X	X	X
06051	X	X	X	X	X	X	X
06052	X	X	X	X	X	X	X
06053	X	X	X	X	X	X	X
06054	X	X	X	X	X	X	X
06055	X	X	X	X	X	X	X
06056	X	X	X	X	X	X	X
06057	X	X	X	X	X	X	X
06058	X	X	X	X	X	X	X
06059	X	X	X	X	X	X	X
060510	X	X	X	X	X	X	X
060511	X	X	X	X	X	X	X
060513	X	X	X	X	X	X	X
060514	X	X	X	X	X	X	X

Component Mission Profile Matrix

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
0607		X	X	X	X	X	
06071		X	X	X	X	X	
06072		X	X	X	X	X	
06073		X	X	X	X	X	
06074		X	X	X	X	X	
06075		X	X	X	X	X	
06076		X	X	X	X	X	
06077		X	X	X	X	X	
06078	X	X	X	X	X	X	X
06079	X	X	X	X	X	X	X
060710	X	X	X	X	X	X	X
060711	X	X	X	X	X	X	X
0609							
06091							
06092							
06093	25% of Total Mission Time						
06094							
06095							
06096							
0610		X	X	X	X	X	
06101		X	X	X	X	X	
06102		X	X	X	X	X	
06103		X	X	X	X	X	

Component Mission Profile Matrix

Component/ Assembly	Function: Start	Idle	Drive	Lift	Transport	Deposit	Stop
06104		X	X	X	X	X	
06105		X	X	X	X	X	
06106		X	X	X	X	X	
06107		X	X	X	X	X	
0611							
06111							
06112							
06113		2.1% of Total Mission Time					
06114							
06115							
06117							
0612	X	X	X	X	X	X	X
06121	X	X	X	X	X	X	X
06122	X	X	X	X	X	X	X
06123	X	X	X	X	X	X	X
06124	X	X	X	X	X	X	X
06125	X	X	X	X	X	X	X
0613	X	X	X	X	X	X	X
06131	X	X	X	X	X	X	X
06132	X	X	X	X	X	X	X

Component Mission Profile Matrix

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
0708			X		X		
07081			X		X		
07082			X		X		
07083			X		X		
07084			X		X		
07085			X		X		
07086			X		X		
07087			X		X		
07088			X		X		
07089			X		X		
0710			X		X		
07101			X		X		
07102			X		X		
07103			X		X		
07104			X		X		
07105			X		X		
07106			X		X		
07107			X		X		
07108			X		X		
07109			X		X		
071010			X		X		
0713			X		X		
07131			X		X		
07132			X		X		

Component Mission Profile Matrix

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
07133			X		X		
07134			X		X		
07135			X		X		
0714			X		X		
07141			X		X		
07142			X		X		
07143			X		X		
07144			X		X		
07145			X		X		
07146			X		X		
07147			X		X		
07148			X		X		
07149			X		X		
0721			X		X		
07211			X		X		
07212			X		X		
07213			X		X		
07214			X		X		
07215			X		X		
07216			X		X		

Component Mission Profile Matrix

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
0900			X		X		
09001			X		X		
09002			X		X		
09003			X		X		
09004			X		X		
09005			X		X		
09006			X		X		
1000			X		X		
10001			X		X		
10002			X		X		
10003			X		X		
1002			X		X		
10021			X		X		
10022			X		X		
10023			X		X		
10024			X		X		
10025			X		X		
10026			X		X		
10027			X		X		
1100			X		X		

Component Mission Profile Matrix

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
1104			X		X		
11041			X		X		
11042			X		X		
11043			X		X		
11044			X		X		
11045			X		X		
11046			X		X		
11047			X		X		
11048			X		X		
11049			X		X		
110410			X		X		
1204		X	X	X	X	X	
12041		X	X	X	X	X	
12042		X	X	X	X	X	
12043		X	X	X	X	X	
12044		X	X	X	X	X	
12045		X	X	X	X	X	
12046		X	X	X	X	X	
12047		X	X	X	X	X	
12048		X	X	X	X	X	
12049		X	X	X	X	X	
120410		X	X	X	X	X	
120411		X	X	X	X	X	
120412		X	X	X	X	X	

Component Mission Profile Matrix

Component/ Assembly	Function: Start	Idle	Drive	Lift	Transport	Deposit	Stop
120413				X x22%		X x22%	
120414				X		X	
1206		X	X	X	X	X	
12061		X	X	X	X	X	
12062		X	X	X	X	X	
12063		X	X	X	X	X	
12064		X	X	X	X	X	
1201		X	X	X	X	X	
12011		X	X	X	X	X	
12012		X	X	X	X	X	
12013		X	X	X	X	X	
12014		X	X	X	X	X	
12015		X	X	X	X	X	
1202		X	X	X	X	X	
12021		X	X	X	X	X	
12022		X	X	X	X	X	
12023		X	X	X	X	X	
12024		X	X	X	X	X	
12025		X	X	X	X	X	
12026		X	X	X	X	X	
12027		X	X	X	X	X	
12028		X	X	X	X	X	

Component Mission Profile Matrix

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
12029				X x22%		X x22%	
12030		X	X	X	X	X	
1311			X	X	X	X	
13112			X	X	X	X	
13113			X	X	X	X	
13114			X	X	X	X	
13115			X	X	X	X	
13118			X	X	X	X	
13131			X	X	X	X	
13132			X	X	X	X	
1401			X		X		
14011			X		X		
14012			X		X		
14013			X		X		
14014			X		X		
14015			X		X		
14017			X		X		
14018			X		X		

Component Mission Profile Matrix

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
1410			X		X		
14101			X		X		
14102			X		X		
14103			X		X		
14104			X		X		
14105			X		X		
14106			X		X		
14107			X		X		
14108			X		X		
1411			X		X		
1412			X		X		
14121			X		X		
14122			X		X		
14123			X		X		
14124			X		X		
1414			X		X		
14141			X		X		
14142			X		X		
14143			X		X		
14144			X		X		
14145			X		X		
14146			X		X		

Component Mission Profile Matrix

Component/ Assembly	Function: Start	Idle	Drive	Lift	Transport	Deposit	Stop
1501			X	X	X	X	
1502			X	X	X	X	
1601			X	X	X	X	
1602			X	X	X	X	
1801			X	X	X	X	
18011			X	X	X	X	
18012			X	X	X	X	
18013			X	X	X	X	
18015			X	X	X	X	
18062	X	X	X	X	X	X	X
2401				X		X	
24011				X		X	
24012				X		X	
24013				X		X	
24014				X		X	
24015				X		X	
24016				X		X	
24017				X		X	

Component Mission Profile Matrix

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
2402				X		X	
24021				X		X	
24022				X		X	
24023				X		X	
24024				X		X	
24025				X		X	
24026				X		X	
24027				X		X	
24028				X		X	
24029				X		X	
2403				X		X	
24031				X		X	
24032				X		X	
24033				X		X	
2404				X		X	
24041				X		X	
24042				X		X	
24043				X		X	
24044				X		X	
24045				X		X	
24046				X		X	
24047				X		X	
24048				X		X	

Component Mission Profile Matrix

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
2405			X	X	X	X	
24051			X	X	X	X	
24053			X	X	X	X	
24054			X	X	X	X	
24055			X	X	X	X	
24056			X	X	X	X	
24057			X	X	X	X	
24058			X	X	X	X	
24059			X	X	X	X	
240510			X	X	X	X	
240511			X	X	X	X	
240512			X	X	X	X	
240513			X	X	X	X	
240514			X	X	X	X	
2501			X		X		
25011			X		X		
25012			X		X		
25013			X		X		
25014			X		X		
25015			X		X		
25016			X		X		

Component Mission Profile Matrix

Component/ Assembly	Function						
	Start	Idle	Drive	Lift	Transport	Deposit	Stop
2406			X	X	X	X	
24061			X	X	X	X	
24062			X	X	X	X	
24063			X	X	X	X	
24064			X	X	X	X	
24065			X	X	X	X	

FORK-LIFT-TRUCK FUNCTIONAL GROUPING CODES

01 ENGINE SYSTEM

0100 Engine Assembly

- 01001 Attaching Parts
- 01002 Mountings
- 01003 Gasket Sets
- 01004 Rear Seal
- 01005 Accessory Drive
- *01006 Timing Gear Assembly*
- 01007 Ring Assembly
- 01008 Rods/Bearings Assembly
- 01009 Cylinder Sleeves

0101 Crankcase

- 01011 Block
- 01012 Cylinder Head
- 01013 Head Gasket
- 01014 Expander Plug

0102 Crankshaft Assembly

- 01021 Crankshaft Bearing
- 01022 Crankshaft Gear
- 01023 Crankshaft Journal
- 01024 Seal
- 01025 Gear Coupling
- 01026 Pulley

0103 Flywheel Assembly

- 01031 Ring Gear
- 01032 Pilot Bearing
- 01033 End Bell

0104 Pistons

- 01041 Piston Rings
- 01042 Wrist Pin
- 01043 Expander Ring
- 01044 Connecting Rods

0105 Valves

- 01051 Push Rods
- 01052 Rocker Arms
- 01053 Valve Springs
- 01054 Valve Guide
- 01055 Valve Cover
- 01056 Gaskets
- 01057 Camshaft
- 01058 Camshaft Gear
- 01059 Camshaft Key
- 010510 Lifter
- 010511 Camshaft Bearing
- 010512 Spur Gear
- 010513 Nuts, Bolts, misc.
- 010515 P.C. Valve

0106 Engine Lub

- 01061 Gaskets
- 01062 Oil Filter
- 01063 Crankcase Breather
- 01064 Oil Pump
- 01065 Oil Lines, Fittings, etc.
- 01067 Oil Tank
- 01068 Oil Pan
- 01069 Dip Stick

0108 Engine Manifold

- 01081 Gasket
- 01082 Heat Control Shaft
- 01083 Heat Control Thermostat

0109 Engine Accessories

03 FUEL SYSTEM

0301 Carburetor Assembly

- 03011 Gasket
- 03012 Filter Element
- 03013 Needle Valve
- 03015 Float
- 03016 Choke

0302 Fuel Pump

- 03021 Gasket
- 03022 Diaphragm
- 03023 Relief Valve
- 03024 Discharge Valve
- 03025 Bolts, Fittings, etc.

0304 Air Cleaner

- 03041 Cleaner Element
- 03042 Mounting
- 03043 Hose
- 03044 Scoop

0306 Fuel Tank

- 03061 Lines
- 03062 Cap, Strainer

0308 Governor and Control

03081 Plug
03082 Gasket
03083 Seal
03084 Bearing
03085 Linkage
03086 Weights
03087 Bushing
03088 Spring

0309 Fuel Filter

0312 Accelerator Throttle and Choke Control

03121 Linkage
03122 Spring
03123 Connecting Pin
03124 Pedal
03125 Roller

04 EXHAUST SYSTEM

0401 Muffler and Pipe Assembly

04011 Gasket
04012 Muffler
04013 Pipe
04014 Elbow
04015 Clamp
04016 Fittings

05 COOLING SYSTEM

0501 Radiator Assembly

05011 Radiator Cap
05012 Core
05013 Overflow Pipe
05014 Fittings

0503 Water Manifold

05031 Fittings
05032 Hose
05033 Thermostat
05034 Gasket
05035 Thermostat Housing

0504 Water Pump

05041 Gasket
05042 Bearing
05043 Shaft
05044 Hub

0505 Fan Assembly

05051 Blade
05052 Belt
05053 Pulley
05054 Bearing
05055 Fittings

06 ELECTRICAL SYSTEM

0601 Alternator Assembly

06011 Bearing
06012 Brush
06013 Commutator
06014 Mounting Bolts
06015 Wiring

0602 Generator

06021 Commutator
06022 Mounting Bolts
06023 Bracket, Clamp
06024 Brush
06025 Shaft
06026 Bearing
06027 Belt
06028 Brush Holders
06029 End Plate
060210 Fan
060211 Pulley
060212 Gaskets, Belts, Etc.
060213 Voltage Regulator

0603 Starter Assembly

06031 Start Solenoid
06032 Solenoid Switch
06033 Bearings
06034 Brushes
06035 Bendix
06036 Fittings, Etc.
06037 End Plate
06038 Armature
06039 Brush Holder

0605 Ignition Assembly

06051 Contact Set
06052 Rotor
06053 Capacitor (Cond.)
06054 Distributor Cap
06055 Timing Distributor Shaft
06056 Distributor Drive Gear

06057 Centrifugal Advance Weights
06058 Coil (Ign.)
06059 Spark Plugs
060510 Spark Plug Cables
060511 Suppressor
060513 Dust Caps
060514 Distributor Assy

0607 Engine Control Panel

06071 Ammeter
06072 Fuel Gage
06073 Oil Pressure Gage
06074 Hourmeter
06075 Temperature Gage
06076 Light Switch
06077 Transmission Oil Switch
06078 Ignition Switch
06079 Starter Switch
060710 Fuse, Holder, Blocker
060711 Divider (Insulator)

0609 Lights

06091 Headlight
06092 Tail Light
06093 Wiring
06094 Mountings
06095 Seal Beam
06096 Bulbs

0610 Sending Units

06101 Hourmeter (SU)
06102 Oil Pressure (SU)
06103 Water Temperature (SU)
06104 Fuel Gage (SU)
06105 Transmission Oil Temperature Warning Light (SU)
06106 Fuel Tank-SU-Gasket (SU)
06107 Transmission Oil Temperature

0611 Horn Assembly

06111 Button Spring
06112 Horn
06113 Cable
06114 Button Cover
06115 Contact
06116 Horn Button Kit
06117 Relay

0612 Storage Battery

06121 Cell
06122 Terminal
06123 Cable
06124 Cap
06125 Frame, Fittings, Etc.

0613 Chassis Wiring Harness

06131 Connectors
06132 Wire

07 TRANSMISSION SYSTEM

0708 Torque Converter

07081 Gasket
07082 Bearing
07083 Clutch
07084 Packing
07085 Shaft
07086 Pump
07087 Relief Valve
07088 Housing
07089 Shoes

0710 Transmission Assembly

07101 Gears
07102 Bearing
07103 Seal
07104 Screen
07105 Gasket
07106 Hoses
07107 Bracket
07108 Retainer Ring
07109 Shift Cylinder
071010 Neutral Switch

0713 Intermediate Clutch

07131 Gears
07132 Seal
07133 Bearings
07134 Piston
07135 Clutch Spring

0714 Servo Unit

07141 Control Knob
07142 Linkage
07143 Plug
07144 Valve Spring
07145 Seal
07146 Gasket
07147 Plunger
07148 Valve
07149 Tube

0721 Coolers, Pumps, Motors

- 07211 Filter Element
- 07212 Gasket
- 07213 Relief Valve
- 07214 Filter Spring
- 07215 Plug
- 07216 Hose, Fittings

09 PROPELLER AND SHAFT SYSTEM

0900 Propeller and Shaft Assembly

- 09001 Bolts
- 09002 Bearings
- 09003 Shaft
- 09004 Sprocket
- 09005 "U" Joint Kit
- 09006 "U" Joint Assy

10 FRONT AXLE SYSTEM

1000 Axle and Housing

- 10001 Shaft
- 10002 Housing
- 10003 Hydra-Lizer

1002 Differential

- 10021 Roller Bearing
- 10022 Ring Gear/Pinion Teeth
- 10023 Spider Gear
- 10024 Gasket
- 10025 Carrier
- 10026 Seal
- 10027 Cone

11 REAR AXLE SYSTEM

1100 Rear Axle Assembly

1104 Steering Sideshaft and Wheel Leaning Mechanism

- 11041 Steering Axle
- 11042 King Pin Bearing
- 11043 King Pin
- 11044 Fitting
- 11045 Bushing
- 11046 Steering Center Arm
- 11047 Cone and Roller
- 11048 Roller Bearing
- 11049 Cup
- 110410 Seal

12 HYDRAULIC BRAKES

1201 Hand Brake

- 12011 Shear Pin
- 12012 Cable and Clamp
- 12013 Lever
- 12014 Knob
- 12015 Shoes/Band

1202 Service Brake

- 12021 Brake Shoe
- 12022 Retracting Spring
- 12023 Brake Lining
- 12024 Carrier Plate
- 12025 Adjusting Screw
- 12026 Wheel Cylinder Assy
- 12027 Cable Assembly
- 12028 Seals
- 12029 Creeper Pedal or Inching Pedal
- 12030 Clamp

1204 Hydraulic Brake System

- 12041 Hydraulic Brake Line
- 12042 Gasket
- 12043 Wheel Cylinder Boot
- 12044 Cup and Piston
- 12045 Master Cylinder Cup Seal
- 12046 Master Cylinder Piston
- 12047 Master Cylinder Spring
- 12048 Hose
- 12049 Tank Fitting
- 120410 Master Cylinder Assy
- 120411 Wheel Cylinder Kit
- 120412 Master Cylinder Kit
- 120413 Inching Valve Boot
- 120414 Inching Valve Assy

1206 Mechanical Brake

- 12061 Pedal Pad
- 12062 Return Spring
- 12063 Linkage
- 12064 Bearing

13 WHEEL SYSTEM

1311 Wheel Assembly

- 13111 Brake Drum
- 13112 Wheel Bearing

13113 Cup
13114 Wheel Nuts, Bolts, Lugs, Etc.
13115 Seal
13118 Spring
13131 Tires
13132 Tubes

14 STEERING SYSTEM

1401 Mechanical Steering Gear Assy

14011 Tie Rod and End
14012 Bearing
14013 Steering Wheel
14014 Seal
14015 Shaft
14017 Drag Link
14018 Nuts, Bolts, Etc.

1410 Hydraulic Pump

14101 Gears
14102 Seal
14103 Bearing
14104 Relief Valve
14105 Gasket
14106 Drive Belt
14107
14108 Shaft

1411 Hoses, Lines and Fittings

1412 Hydraulic Cylinder

14121 Seal
14122
14123 Piston
14124 Ball Socket

1414 Steering System Valves

14141 Spool
14142 Seal
14143 Dust Cover
14144 Sleeve
14145 P/S Packing
14146 P/S Kit

15 FRAME SYSTEM

1501 Frame Assembly (Operator Protector)

1502 Counterweight

18 BODY SYSTEM

1801 Body Assembly

18011 Hinge
18012 Latch
18013 Structure
18015 Floor Board Assy

1806 Seats

18062 Seat, Back Rest

24 HYDRAULIC LIFT SYSTEM

2401 Hydraulic Lift Pump

24011 Pump Drive Cross Brgs.
24012 Pump Bearings
24013 Seal
24014 Gear
24015 Pump Packing
24016 Hyd. Pump Filter
24017 Pulley

2401 Hydraulic Control Valve

24021 Spring
24022 Seal
24023 Piston
24024 Cap
24025 Hose
24026 Bracket
24027 Valve Cover
24028 C/V Packing
24029 C/V Ring Set

16 SUSPENSION SYSTEM

1601 Springs, Leaf

1602 Clamps, Nuts, Bolts, Etc.

2403 Hydraulic Controls, Levers, Linkage

24031 Spring
24032 Linkage Pin
24033 Level, Link or Rod

2404 Hydraulic Tilt Cylinder and Cranks

24041 Packing
24042 Tilt Cylinder Assy
24043 Linkage

24044 Packing Nut
24045 Hose
24046 Ring
24047 Cup
24048 Kit

2405 Hydraulic Mast Column Assy

24051 Packing L/C
24052 Cylinder
24053 Roller Bearings
24054 Pins
24055 Chains
24056 Package Rack
24057 Ring
24058 Inner Slide
24059 Brace
240510
240511 Flange Assembly
240512 Bolt, Clamp
240513 Packing Nut
240514 Forks

2406 Hydraulic Lines and Fittings

24061 Lines
24062 Filter Element
24063 Filter Gasket
24064 Filter Spring
24065 Hydraulic Fluid Tank

2501 Clutch System (Transmission)

25011 Pedal
25012 Spring
25013 Plate Assembly
25014 Linkage
25015 Disc Assembly
25016 Bearings

APPENDIX B

TYPICAL 30-DAY MACHINE SERVICE-CALL RECORD FOR DGSC RICHMOND, VIRGINIA

Typical 30 Day "Machine Service Call" Record
DGSC, Richmond, Virginia

Lift Number	Type of Trouble	Parts Used or Remarks	Repair Time (Hours)
124R	Leaking oil	Blowing oil out of breather Brought to shop	1.0
124R	Won't start	Started lift, adjusted carb.	1.0
129R	Won't start	Started lift	1.0
143R	Leaking oil	Check and sent to shop for badly leaking hydraulic oil hose	.5
182R	Won't start	Started lift, adjusted power steering belt	1.0
185R	Won't start	Started lift	1.0
191R	Won't start	Started lift	1.0
343R	Won't start	Started lift	1.0
378R	Clock not working	Checked hour meter, reading 1812	.5
378R	Won't start	Started lift	1.0
590R	Leaking oil	Taken to shop for repairs	1.0
590R	Won't start	Unlocked starter, repaired wires	1.0
651R	Won't start	Started lift	1.0
654R	Leaking oil	Checked, will have to be brought to shop for repairs	.5
695R	Won't go in reverse	Adjusted and repaired gear shift linkage	1.0
108R	Leaking radiator hose	Installed bottom radiator hose	1.0
181R	Busted head light	Installed mast light, box fell on light during unloading	1.0
173R	Bad clutch	Adjusted creeper brake and clutch	1.0
182R	Leaking oil	Removed and repaired oil filter	1.0
687R	Flat tire	Repaired flat tire	1.0
695R	Engine missing	Cleaned spark plugs, cleaned and adjusted points (replaced four plugs	1.0
		(continued)	

APPENDIX B (continued)

Lift Number	Type of Trouble	Parts Used or Remarks	Repair Time (Hours)
100R	Lift making noise	Lift continued to make noise, can be used until scheduled maintenance	.5
104R	Transmission linkage	Adjusted linkage on master cylinder	1.0
120R	Loose exhaust	Repaired exhaust line	1.0
156R	Won't start	Started lift after getting gas	1.0
341R	Flat tire	Repaired flat tire	1.0
343R	Gear shift out of connection	Replaced ball joint on gear shift linkage	1.0
346R	Flat tire	Repaired tire	1.0
515R	Won't start	Started lift, adjusted idling	1.0
651R	Won't start	Unlocked starter	1.0
343R	Won't start	Started lift	1.0
100R	Won't start	Water pump gone bad, fan blade broken off, sent to shop	.5
110R	Fire extinguisher bad	Replaced fire extinguisher	.5
115R	Won't start	Started lift, adjusted voltage regulator	1.0
138R	Lift chain off	Replaced chain on rollers	.5
169R	Mast light broken	Repaired wires to spot light	1.0
177R	Won't start	Started lift after charging battery	1.0
349R	Flat tire	Repaired flat tire and replaced lug bolt	1.5
350R	Light out	Replaced burned out bulb	.5
653R	Won't start	Started lift	1.0
695R	Won't start	Unlocked starter, installed 4 spark plugs	1.5
105R	Engine cuts off	Replaced ignition wires	1.0
121R	Light out	Replaced seal beam	1.0
125R	Forks won't lower	Repaired safety lock on lift to let forks down, bad gas gauge, sent to shop	1.5

(continued)

APPENDIX B (continued)

Lift Number	Type of Trouble	Parts Used or Remarks	Repair Time (Hours)
180R	Won't start	Cleaned and serviced air filters; started lift	1.0
126R	Light out	Replaced seal beam	1.0
134R	Muffler loose	Repaired exhaust system	1.0
138R	Operator protector	Removed and replaced guard	3.0
142R	Lights out	Repaired short in mast light	1.0
145R	Tilt out	Repaired tilt control by installing cotter lug	1.0
174R	Hard steering	Installed P/S belt	1.0
189R	Won't start	Checked and brought to shop for repairs	1.0
378R	Hour meter not working	Checked hour meter; reading 1820	1.0
378R	Light out	Replaced mast light wires	1.0
695R	Won't start	Checked and brought to shop to repair starter	1.0
120R	Won't start	Started lift	1.0
192R	Won't start	Started lift	1.0
119R	No brakes	Repaired and adjusted brakes	1.0
125R	No gauges working	Repaired burned wires under dash board	1.5
126R	Won't start	Started lift	1.0
142R	Won't start	Started lift, reset voltage regulator	1.0
145R	Won't start	Started lift	.5
168R	Flat tires	Brought to shop	1.0
184R	Light out	Replaced seal beam	1.0
347R	Flat tire	Repaired flat tire	1.0
378R	Won't start	Started lift	1.0
376R	Won't start	Started lift	.5
122R	Sealing oil	Hose broken hydraulic system, sent lift to shop	1.5
158R	Won't start	Unlocked starter and started lift	1.0
		(continued)	

APPENDIX B (continued)

Lift Number	Type of Trouble	Parts Used or Remarks	Repair Time (Hours)
168R	Gas gauge Inoperable	Sending unit back - will be repaired on next scheduled maintenance	.5
653R	Won't start	Repaired wire to voltage regulator, started lift	1.0
113R	Brake out	Adjusted and repaired brakes	1.0
120R	Exhaust loose	Repaired exhaust system	1.0
122R	Won't move	Strapping tangled in drive wheel, removed and replaced left drive wheel	1.5
128R	Started dragging	Checked; starter bad but still serviceable - check on next inspection	.5
129R	Won't start	Started lift	.5
131R	Won't start	Adjusted voltage regulator and started lift	1.0
131R	Won't start	Checked transmission and started lift	1.0
142R	Won't start	Started lift	1.0
155R	Battery cable	Cleaned and repaired battery terminals and cable ends	1.0
168R	Leaking hydraulic fluid	Replaced ruptured hydraulic hose	1.0
348R	Tail pipe broken off	Replaced exhaust pipe	1.0
515R	Won't start	Started lift (boosted)	.5
590R	Won't start	Unlocked starter and started lift	1.0
186R	Light out	Repaired and tightened head light, replaced seal beam	1.0
347R	Won't start	Started lift, charged battery	1.0
350R	Clutch bad	Checked and brought to shop for repairs	1.0
124R	Carburetor out of adjustment	Repaired accelerator linkage	1.0
115R	Light out	Replaced seal beam	1.0
		(continued)	

Lift Number	Type of Trouble	Parts Used or Remarks	Repair Time (Hours)
124R	Idling too fast	Repaired accelerator linkage to carburetor	1.0
678R	Flat tires	Repaired two flat tires	2.0
678R	Won't start	Installed fan belt and started lift	1.0
346R	Guard broken	Welded operator protector	1.0
350R	Won't start	Filled battery with water, started lift	1.0
683R	Won't start	Started lift	1.0
142R	Won't start	Started lift	1.0
347R	No brakes	Checked, carried to shop for repairs	1.0
122R	Won't lift	Checked hydraulic lines, filled hydraulic tank	1.0
123R	Loose fan belt	Tightened belts	1.0
345R	Won't start	Started lift	1.0
515R	Dead battery	Replaced battery	1.0
104R	Broken fan belt	Installed set of fan belts and straightened fan blades	1.5
129R	Leaking oil	Repaired oil leak at filter	1.0
145R	Tilt control liner	Repaired tilt control liner and repaired clevis pin	1.0
171R	Won't start	Started lift (boosted)	.5
180R	Flat tire	Repaired flat tire	1.0
343R	Flat tire	Repaired right steering tire	2.0
343R	Hard starting	Tuned engine	2.0
590R	No power	Replaced governor	1.0
122R	Won't start	Repaired neutral starting switch, started lift	1.0
126R	Won't start	Started lift (boosted)	.5
128R	Leaking hydraulic fluid	Tightened hydraulic lines and nuts to hoist cylinder	1.0
129R	Muffler ruptured	Oil leak, checked and sent to shop for repairs	.5
		(continued)	

APPENDIX B (continued)

Lift Number	Type of Trouble	Parts Used or Remarks	Repair Time (Hours)
137R	No brakes	Repaired brakes	1.0
343R	Running hot	Cleaned and flushed radiator with solvent and installed antifreeze	2.0
171R	Won't start	Installed voltage regulator, started lift	1.0
174R	Leaking hydraulic fluid	Tightened hose fittings to tilt cylinder	1.0